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An MRI Compatible Surface Scanner

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Objectives

We propose the hardware design of an optical surface scanner for in-bore monitoring and markerless tracking of surfaces. It is the first remote structured light scanner that transmits projected patterns onto the subject and captures their images through optical fiber bundles.

The system is named Tracoline 2.0 and is a modified version of our first system demonstrated for PET brain motion correction [1]. Tracoline 2.0 is designed to be MRI compatible and produce real time in-bore surface scans.

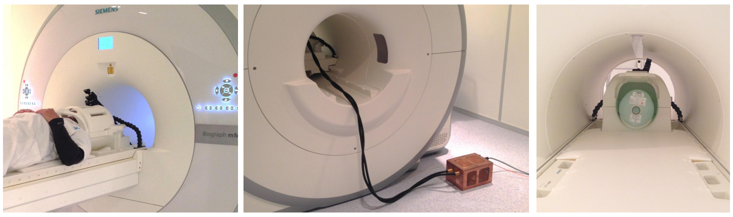

Fig. 1: Tracoline 2.0 was set up on the Siemens mMR Biograph 3T scanner to demonstrate its feasibility in the narrow in-bore geometry further challenged by the limited view of the standard mMR head coil.

Methods

To achieve a compact, RF noiseless, and low attenuation device, the electronics are separated from the optical end by two 670×500 image fibers of 2.7 m. A minimum of components are located in-bore, while the RF emitting and ferromagnetic components are kept out of the bore.

The system consists of: 1) a computer located outside the magnet room, 2) a power unit, also outside the scan room, 3) a system box comprising a camera with a near infrared (NIR) sensitive sensor, a DLP light projector, reengineered to project invisible NIR light, 4) two image fibers, and camera optics which extend from the system box into the bore and transfer the projection image into the bore and the captured image out (Fig.2).

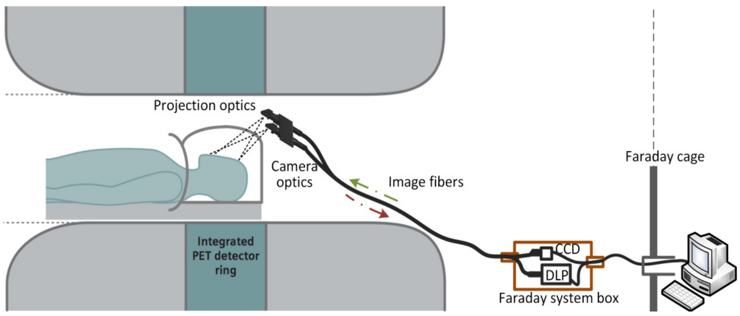

Fig. 2: The developed structured light system integrated with the mMR Biograph.

The MRI compatibility of our system was tested by acquiring MPRAGE and EPI sequences of a cylindrical phantom with the surface scanner: off/out-bore, on/out-bore, off/in-bore, and on/in-bore, respectively. Twenty-four scans were acquired: each of the four combinations repeated six times. The scan parameters were: matrix of 64x64, 35 slices (z), thickness of 4 mm, 100 time series, TR of 3 s, and TE of 30 ms.

Signal-to-Fluctuation-Noise Ratio (SFNR) and Signal-to-Noise Ratio (SNR) were estimated according to [2-3]. A central ROI of L pixels were evaluated.

$$\mathrm{SFNR}_z = \frac{1}{L}\sum_{i=1}^{L}\frac{\mathrm{I}_{\mathrm{signal},z}}{\mathrm{I}_{\mathrm{TFN},z}}, \qquad \mathrm{SNR}_z = \frac{1}{L}\sum_{i=1}^{L}\frac{\mathrm{I}_{\mathrm{signal},z}}{\mathrm{I}_{\mathrm{SSN},z}}$$

- $\mathbf{I}_{\mathrm{signal},z}$: Image Signal - average across the time points.
- $\mathbf{I}_{\mathrm{TNF},z}$: Temporal Fluctuation Noise Image - standard deviation (SD) of the residuals of the detrended signal.
- $\mathbf{I}_{\mathrm{SSN},z}$: Static Spatial Noise Image - the difference of the sum of the even image slices and the sum of the odd image slices.

To demonstrate its feasibility for tracking a volunteer was moving his head arbitrarily inside the mMR, while the Tracoline system was streaming 3D point clouds of the volunteer's face. The head position was estimated relative to the first frame using a robust ICP alignment. The principal was as in [1,4] but faster and with improved system calibration and alignment procedures.

Results

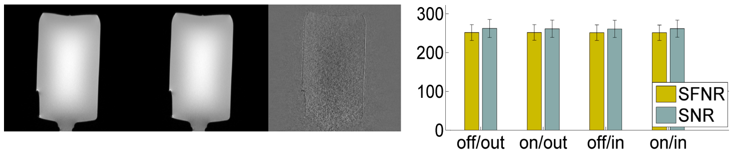

Fig. 3: Left: MPRAGE images of a cylindrical phantom. Left to right: Tracoline off/out-bore, on/in-bore, difference of the first two images. Right: Bar plot of the SNR and SFNR for the fMRI scans. Each group is a mean of all the slice positions and six scan repetitions.

A two sided ANOVA test for the SFNR and SNR show no significant difference between on/off and in/out-bore based on a linear model including time of the scanning as a factor.

Despite the limited view of the standard mMR Biograph head coil, 3D point clouds of the face region around the nose bridge was captured during motions of up to 30 mm translation and 10 degrees rotation (Fig. 5).

The optical image fibers add noise to the surface reconstruction compared to systems without fibers. However, the quality of the 3D point clouds are still impressive as seen on Fig. 4 with the details of the small structures.

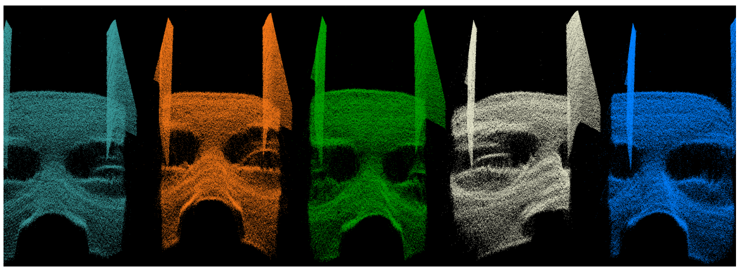

Fig. 4: Snapshots of 3D point clouds of a volunteer moving his head inside the mMR Biograph. The head coli is seen in the top as vertical bars.

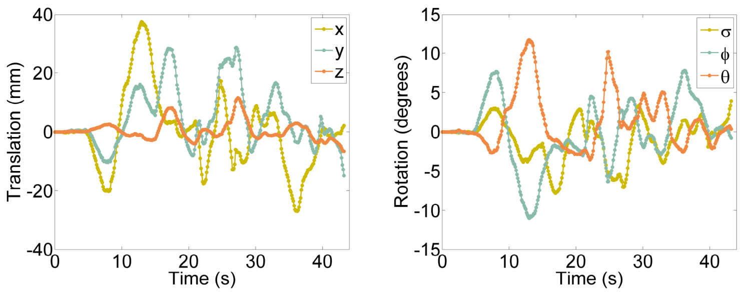

Fig. 5: Motion plots of the volunteer's head motion inside the mMR Biograph. The Tracoline system was streaming 3D point clouds with 8.4 Hz.

Conclusions

We have presented a remote surface scanner with flexible optical image fibers suitable for in-bore applications. The system design was shown to be MRI compatible and functional on the Siemens mMR Biograph.

This technology, together with fast surface alignment algorithms, allow e.g. real-time motion correction feedback without the use of MR navigators or optical markers.

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